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An Economic Analysis of Hay Harvesting and Utilization Using a Simulation Model

by

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SUMMARY AND CONCLUSIONS

This study assessed the effect of the forage harvesting system; the date that harvest begins; the weather pattern; the method of grain feeding; and the size of herd on farm income. Simulation techniques were used to represent forage harvesting, feeding dairy cows, selling or buying forage, and output of milk. The simulation model as developed for this study was comprised of 5 computer programs written in FORTRAN with FORMAT. The model was built in 3 stages: Stage I simulated mowing and harvesting of forage by date of cut and recorded the resources used to perform these operations; Stage II simulated the production of milk using the forage produced in Stage I and recorded the resources used; and Stage III economically related Stage I and Stage II and presented income and resource use statements.

A major advantage of simulation analysis with computers is the speed of analysis completion after the simulation model has been developed. The methods used are similar to those of the conventional budget techniques. The data used are the same, and the data problems are comparable, but much less time is required for the analysis.

When coefficients for the simulation analysis model were developed for forage production, quality and quantity relations as influenced by starting date of cut, milk production according to quality of forage, and labor and machinery productivity were considered. In performing the analysis, particular emphasis was placed upon the development of relation between systems of harvesting forage, quality-quantity forage production, and dairy cow milk responses to quality of forage. The analysis was carried out in 2 phases. Phase I analyzed the interactions of 6 hay harvesting systems, 3 grain feeding systems, 3 cow number options, 3 harvest starting dates, and 3 weather patterns representing "wet," "dry," and "average" conditions during the harvesting season. In Phase II, only 2 hay harvesting systems, a single grain system, and 52 weather patterns were used. Phase I was designed to evaluate harvest systems and select the most profitable combinations. Phase II was designed to study more weather patterns to obtain variations in income for each starting date of cut as influenced by weather.

Based on available data and the analysis made for this study, there is no economic justification for beginning hay operations as early as June 1. However, substantial declines in net farm income are encountered by postponing the beginning of the hay operation to as late as June 30. These observations held for all harvesting systems analyzed. The results indicated that the optimal date, economically, to begin harvesting operations appears to be around June 15.

There were 6 machinery systems analyzed; 4 were capable of harvesting hay in one day. Of these 4 systems, the crushed, baled, and barn dried with heat, and the flail cut, flail harvest were about equal in net income; the grass silage system was not quite as profitable; and the system using heat drying was considerably less profitable. Of the two remaining systems (that rely on natural field curing) the method using a crusher was more profitable.

The crushed, field cured, and baled and the crushed, field cured, and barn dried without heat methods were chosen to represent the two basic harvest systems for the analysis of date of cut and weather patterns on farm income. The barn drying hay-in-a-day harvest system produced less variability in net income when related to the weather patterns during the harvest seasons from 1910 through 1961. The average net income under the variable weather patterns for each of the beginning dates of cut was larger with this system than the system that included field curing.

For a typical dairyman with a herd of approximately 75 cows and 100 acres of hay land, it would be profitable to aim toward a harvest system that would mechanically cure hay in a day.

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CLIFTON C. CLOUD, GEORGE E. FRICK, AND R. A. ANDREWS[1]

INTRODUCTION

The most important forage fed New Hampshire dairy cows is hay. In 1964, of the 168,044 harvested cropland acres, 142,989 acres (85 percent) were harvested as hay.[2] Another 10,694 acres (6 percent) were harvested as corn silage or grain. Almost all hay harvested is fed during the 210-day winter feeding period. The importance of hay in feeding programs suggests that the organization of forage harvest as it affects the quality and quantity of hay harvested could substantially influence the total income, total cost, and net income of a dairy operation. Knowledge of the extent of this influence on net farm income would aid farmers in planning their farm operation.

In this study, simulation techniques were used to analyze the effect of different harvesting systems on net farm income. Major emphasis was given to dates of harvest of the first crop of hay with typical equipment complements.

The Technological Features of Forage Growth

The major technological features of forage growth can be briefly stated as follows:

First, the earlier the date of cut, the higher percentage of digestible dry matter (DDM) in each unit of forage harvested. The percentage of DDM reflects the quality of the forage; high quality forage has a high percentage of DDM. The quantity (tons) of forage harvested per unit of land increases with progressively later dates of harvest.

Second, cows will consume greater quantities of early-cut than later-cut hay crops. During the barn feeding period about one-half ton more early-cut (high DDM value) forage than late-cut (low DDM value) forage will be consumed per cow.

Third, the rate of feeding grain in combination with the varying quality of forage directly affects the amount of milk produced. When

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[2] U. S. Census of Agriculture, Bureau of Census, U. S. Department of Commerce, Vol. I, Part 2, 1964.

the quality (DDM value) of the forage declines, increased amounts or higher quality of grain must be fed to prevent reduced milk production.

Fourth, the weather pattern (the combination of clear and rainy days) during the forage harvesting period influences the length of the harvesting season. Thus, the quality and quantity of forage harvested varies in response to the length and frequency of rain-free day periods during the harvesting season.

Recent research in dairy nutrition summarizes the effect that date of cut has upon nonrow crop forage as follows:[3]

> The date at which first growth forage is harvested is the major known determinant of the intake and digestibility of forage by ruminants. At least within a given climatic region, the digestibile energy (or matter) value of first-grown forage can be predicted quite accurately. Species of plant, methods of preservation (provided that leaf loss is not disproportionate), and physiological growth stage have very little or no effect upon the relationship between cutting time and the DDM value (digestible dry matter value) of forage.
>
> As growth approaches maturity, the DDM value of aftermath forage declines much more slowly that that of first-growth forage. Regardless of its stage of growth, aftermath forage has a lower DDM value than first growth forage harvested prior to June 10 in the northeastern states.

Colovos reports that "The decrease in digestibilities of dry matter. protein, energy, and total digestible nutrients averaged about one-half of 1 percent per day of delay after the first of June."[4] This study was done using dairy steers rather than milk cows. Assuming that the same relation holds, this research indicates that if the DDM value from sources other than forage is held constant, the milk produced from a unit of early-cut forage will be greater than from a unit of late-cut forage. Also, milk obtained from a unit of aftermath forage will not be as much as from a unit of "first-cut" harvested before June 10.[5] Milk output per cow, on the other hand, will be greater from a unit of aftermath forage than from "first-cut" harvested after June 10. The decline in milk production as the date of cut advances occurs because: (1) the cows will not consume as much (unit weight) of the late-cut forage as they will of the early-cut forage, and (2) the DDM value per unit of forage consumed declines as the date of cut advances. These calendar time periods as reported are applicable to conditions in the Northeastern part of the United States.

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[3] Reid, J. T., et. al., "Our Industry Today: Effect of Growth Stage, Chemical Composition and Physical Properties on Nutritive Value of Forage," *Journal of Dairy Science*, 42:567, 1959.

[4] Colovos, N. F., et. al., *The Effect of Nitrogen Fertilization and the Rate of Harvest on Yield, Persistency, and Nutritive Value of Bromegrass Hay, II. Nutritive Value*, New Hampshire Agr. Expt. Sta. Bul. 472, p. 15, 1961.

[5] First cut is first growth forage.

In the Northeastern United States, when harvest is begun very early in the season, 2 difficulties are encountered: (1) Although the quality (DDM value) per unit of forage harvested is high, the quantity (tons) of forage harvested per acre is very low, and (2) the number of rainy days is usually high at this time of the year (May 30 to June 10).[6]

Weather Pattern

The sequence of clear and rainy days that occur during the harvesting season is of great importance because of its influence on the length of the harvest period and the quantity of rain-damaged hay. The average number of clear days, occurring during the 2-month period of June and July at Concord, New Hampshire, for example, varied from a low of 31 to a high of 50 days over the last 50 years.[7]

The weather pattern influences the quality and quantity of forage harvested in the following manner: First, if rainy days are numerous during the harvesting period, harvesting is prolonged, providing time for the quantity (yield per acre) of the forage to increase while the overall quality decreases. Second, if clear days are numerous during the harvesting period, harvesting occurs relatively fast and the quality of each unit harvested is relatively high while the quantity harvested tends to be low. While the absolute number of clear days determines the number of days of harvest operations, the sequence of clear days alters the quality and quantity of hay harvested. The quantity of rain-damaged hay is greater for systems requiring a longer field drying period. For any particular weather sequence the date harvesting commences also influences the quantity and quality of forage harvested. By changing the date that harvesting begins, a different sequence of clear and rainy days is encountered during forage harvest. For example, Figure 1 shows that: (1) if starting date 1 is used, only 2 out of 6 mowings are harvested without getting wet; (2) if starting date 2 is used, 3 mowings are harvested without getting wet; and, (3) if starting date 3 is used, only 1 of the 6 mowings would get wet.

Equipment Complement

The working speed of the equipment complement influences the quality and quantity of the forage harvested by affecting the time required to harvest a unit of forage. Each equipment complement has a specific input-output relationship, and changing from one set of equipment to another changes the resources used and products produced from a given number of acres.

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[6] For the last 49 years, 4 out of the first 10 days of June were rainy on the average with a range from zero to 8.

[7] *Local Climatological Data with Comparative Data*, Concord, New Hampshire, U. S. Department of Commerce, Weather Bureau, 1914 through 1962.

Figure 2 illustrates the effect on the quality and quantity of forage harvested from a change in the equipment complement, everything else held constant. An equipment complement that requires 2 days of field curing time is compared with another that requires only 1 day of curing. By this shift (1) the harvesting period is shortened from 28 to 13 days, and (2) the number of mowings that are rain damaged decrease from 4 out of 6 to zero out of 6.

The Economic Problem of Forage Harvesting and Utilization

The interrelations between the weather pattern, the date that harvest begins, and the harvesting system have an economic significance. The optimum condition is the equipment complement and starting date of harvest for a seasonal weather pattern or sequence of seasonal weather patterns that will produce harvested forage of a quantity and quality that, when fed in combination with grain to cows, will produce the largest net farm income. Variations in labor requirements of various harvesting systems is important.

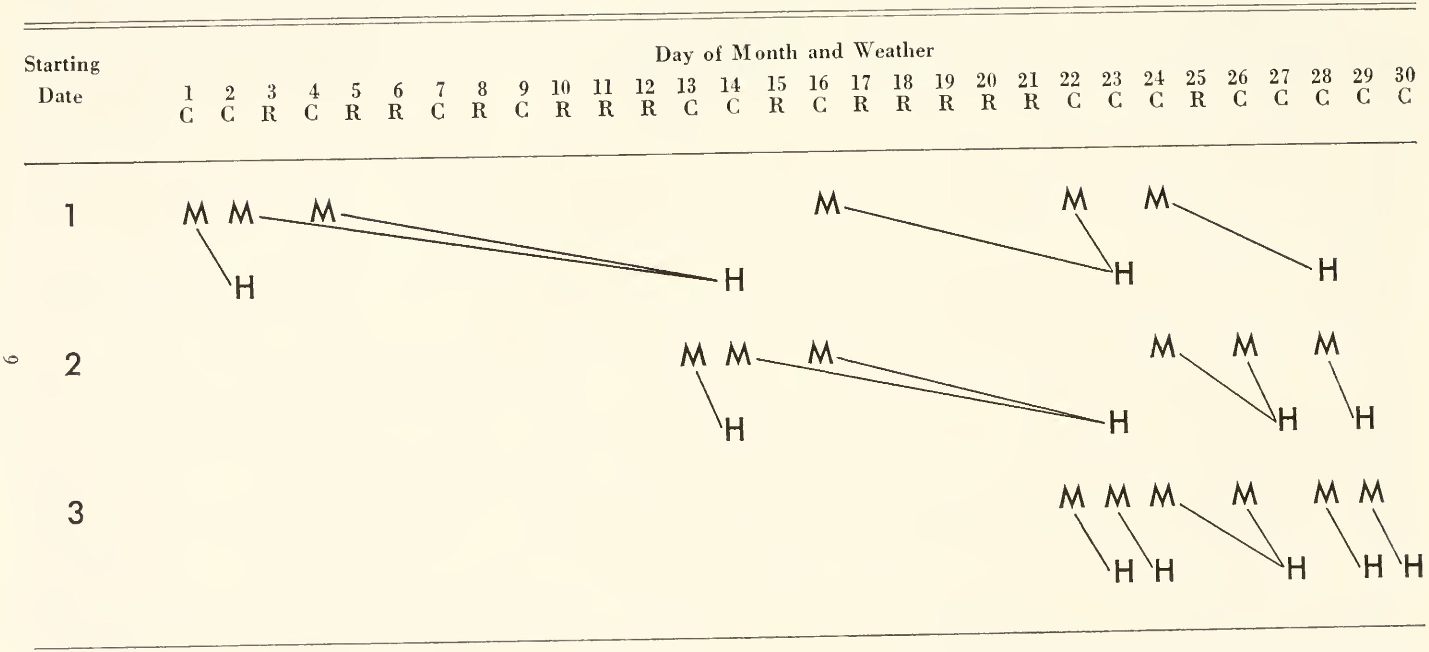
Gross farm income will change as the organization of a harvesting system changes because different quantities and qualities of harvested forage will produce different amounts of milk. The organizational changes may be in the harvesting equipment or in the beginning date of harvest; both factors are associated with a particular weather pattern.

Differences in gross income may also result from changes in the quantities of the resources used in the conversion of forage into milk, such as: (1) changing grain feeding; (2) maintaining herd size while buying or selling forage; or (3) allowing herd size to vary depending on home-grown forage. Net income will also vary with resource organization but not necessarily in proportion to gross income.

Analytical Procedure

A simulation model, consisting of a series of 5 FORTRAN computer programs, was developed to simulate forage harvesting and utilization systems for a dairy farm. Relevant input-output data used in the model were obtained from many sources that are designated in the appropriate sections. Milk response data and crop yield data were synthesized to develop the relevant production relations incorporating forage quality and quantity. The simulation model was designed to make particular use of the quality-quantity production relations. The model also considered various systems of harvesting hay and feeding grain. The effect of varying these conditions as well as the effect of weather patterns and date of cut were measured in terms of physical product output and income.

Figure 1. Days That Mowing and Harvesting Can Occur for Selected Starting Dates in a Typical Weather Pattern*



* R = Rain, C = Clear, M = Mow, H = Harvest. Assumptions — one day work load is a mowing and a harvest or two harvests; if forage is rained on, two clear days in succession are required to harvest; mow every clear day except when two mowings are down; can not predict the weather.

Figure 2. Days That Mowing and Harvesting Can Occur with Two Machinery Complements in a Typical Weather Pattern*

Machinery Complement	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
	C	C	R	C	R	R	C	R	C	R	R	R	C	C	R	C	R	R	R	R	R	C	C	C	R	C	C	C	C	C
1	M	M		M												M						M		M						
		H												H									H					H		
2	M	M		M			M		M				M																	
	H	H		H			H		H				H																	

* R = Rain, C = Clear, M = Mow, H = Harvest. Assumptions — one day work load is a mowing and a harvest or two harvests; if forage is rained on, two clear days in succession are required to harvest; mow every clear day except when two mowings are down; can not predict the weather. Machinery complement drying time is one day of mowing; complement 2 is a hay-in-a-day system.

THE FORAGE PRODUCTION-UTILIZATION SIMULATION MODEL

The model simulated harvesting forage, feeding dairy cows, buying and selling forage, and output of milk. The model treated each production process separately (Figure 3), was designed so that most forage harvesting systems (except for corn) could be simulated, and also provided for several grain feeding practices.

Computer Programs

The model was comprised of 5 computer programs written in FORTRAN with FORMAT for a 1620 IBM digital computer. These programs may be used with any computer that can compile FORTRAN with FORMAT programming language and has a memory unit of at least 40K.[8] The programs were written so that all the input-output coefficients were controlled by the operator. The model was built in 3 stages.

Stage I

Forage production, harvest, and storage were simulated in Stage I. Because of the complexity of these operations, Stage I was written in three programs. Program I simulated the production, mowing, and harvesting of forage by quality and quantity using 2 different systems that required more than 1 day to field-cure the forage. These systems were: field-cured baled, and crushed field-cured baled. Each time a new situation was processed, the program produced the following output: (1) the name of the system and weather pattern used; (2) the day, type, and amount (quality and quantity) of forage that was mowed and harvested; and (3) the amount of resources used to mow and harvest all the forage.

Program II used the output from Programs I and II as input and further classified the forage harvested as to quality. For each situation the program produced the following output: (1) the name and number of the system and weather pattern used, (2) the day, type, and amount (quality and quantity) of first-crop forage, (3) the day (assigned to second crop to make its value, in terms of DDM, proportionate to same day of first crop), type, and amount (quality and quantity) of second crop, and (4) the amount of resources used to mow and harvest all the forage.

Stage II

Program IV, the only program in Stage II, used the output from Program III as input in the simulation of milk production under farm

[8] For programs in FORTRAN, see *A Simulation Model of Forage Production and Utilization* by C. C. Cloud, R. A. Andrews, and G. E. Frick, D.R.E., Agr. Expt. Sta., University of New Hampshire, Special Report No. 5.

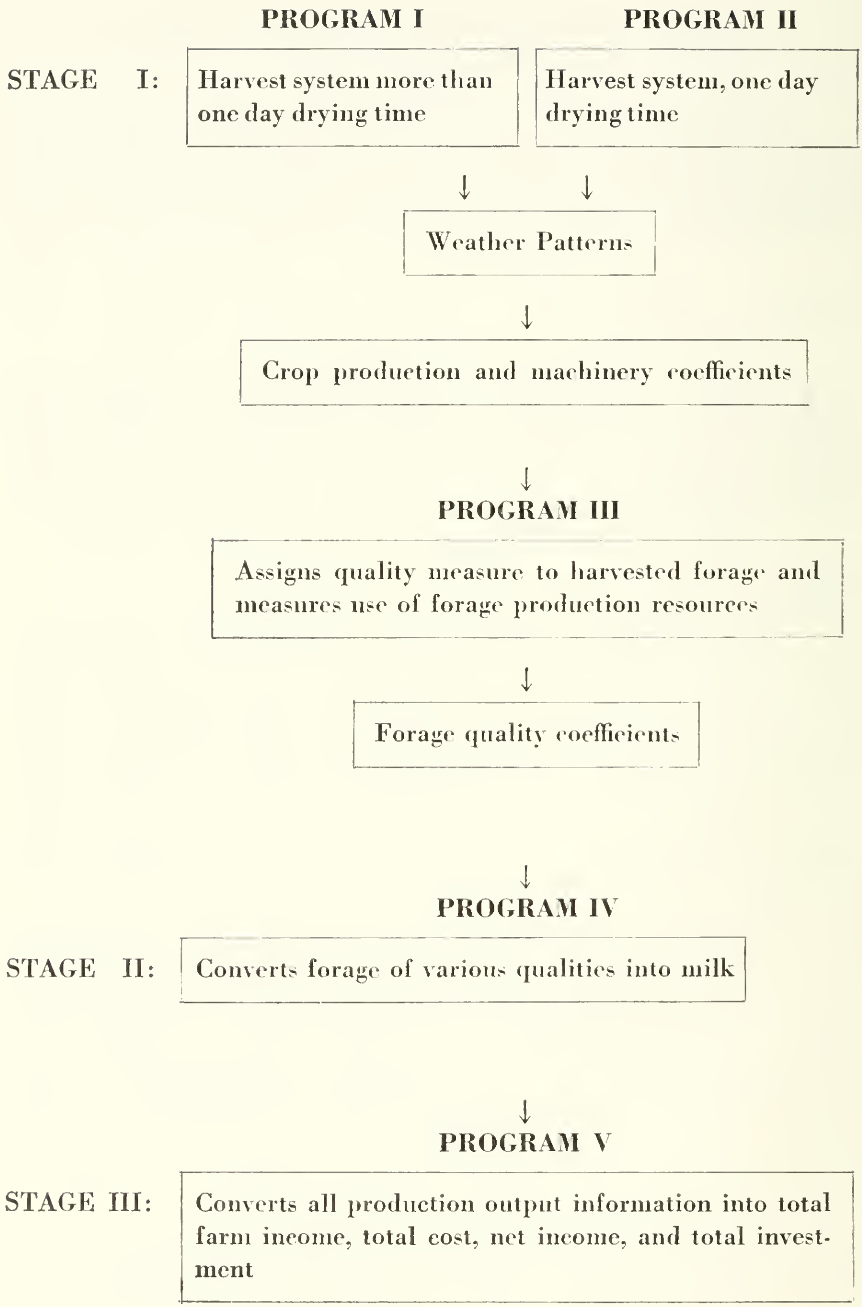


Figure 3. A Schematic Outline of the Forage Production — Utilization Simulation Model

conditions,[9] and also determined the amount of resources used in the production of this milk. Milk production varied with quality of forage, herd size, and grain feeding practices.

Stage III

Program V, the only program in Stage III, used the output from Program IV (the total resources used and products produced for each combination of weather pattern, starting date, system, and method of producing milk) as input. This program determined the total income, total cost, net income, and total investment for the combinations analyzed.

DATA AND ASSUMPTIONS FOR THE ANALYSIS

The coefficients necessary to evaluate the harvesting systems and the alternate methods of feeding grain are developed in this section. These coefficients controlled the computer programs for simulating farm conditions by specifying such things as: how many acres could be mowed in a day; what losses occurred for each system; what date mowing started; what weather patterns were assumed; how many labor and machinery hours were needed to mow and harvest an acre of land; and how many man-hours were required to milk, feed, and care for cows.

Acreage

In this study, 100 acres of forage was the basis for analysis of harvesting and utilization. Each acre received the same application of fertilizer, contained the same species of plant, and the yield per acre was the same on any date for all systems.

Forage Crop Yield

The only source of variation in forage crop yields considered was date of cut of the first crop harvested. Research in the Northeast indicates yield increases (at a decreasing rate) as harvest date advances

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[9] Because there are many management methods possible in the production of milk, no single method would be ideal for all circumstances. The program written allowed the operator to combine the resources in 6 different ways. Variation in herd size and method of feeding were permitted. Herd size could be held constant with forage deficits and surpluses adjusted for by hay purchases and sales; or herd size could be allowed to vary with size being determined by quantity of forage available. See Clifton C. Cloud, "The Effect of Alternative Harvesting Methods on the Qualities and Quantities of Forage Harvested and on the Production of Milk and Net Farm Income," unpublished M.S. thesis, University of New Hampshire.

from June 1 into the summer.[10] Comparison of these dates revealed a large degree of similiarity in yield behavior between areas as to calendar date (Figure 4). A second degree equation was fitted to these yield

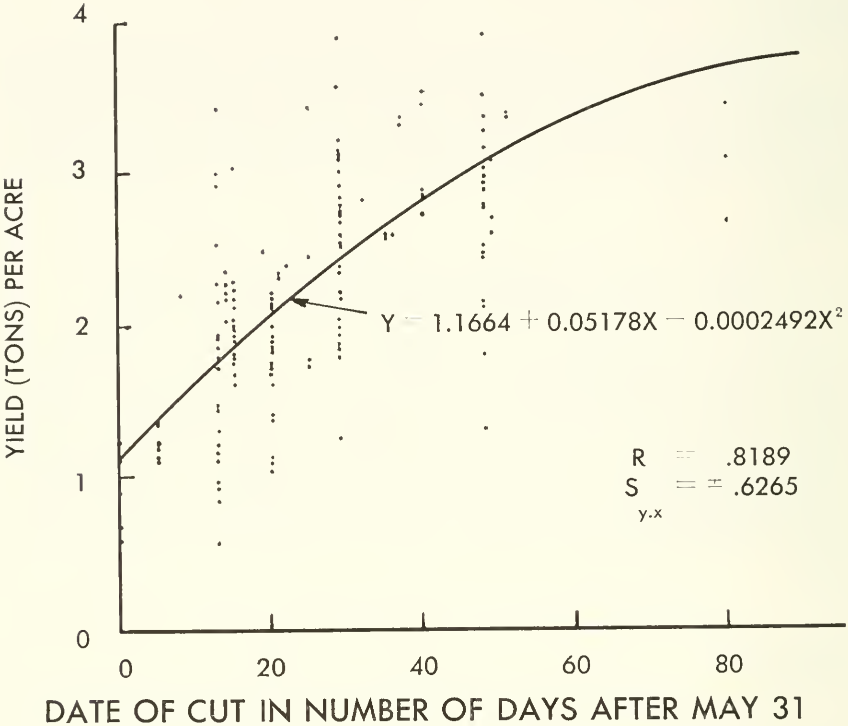

Figure 4. Relation Between Date of Cut and Yield Per Acre of First Crop Forage

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[10] Kennedy, W. K., *Nitrogen Fertilization of Meadows and Pastures*. Cornell Agr. Expt. Sta. Bul. 935, 1958.

Colovos, *et. al., op. cit.*

Rakes, *et. al., The Feeding Value for Milk Production of Hays Cut at Various Dates*. W. Va. Agr. Expt. Sta. Current Rpt. 35, 1962.

Rask, *et. al., Early Cut Hay and Silage: Cost and Returns*. Cornell Ext. Bul. 1059, 1961.

Regional Forage Crops, Northeast Regional Project NE-21, University of Rhode Island, Agr. Expt. Sta. Bul. 356, 1960.

Ross, V. E. and Fellows, I. F. *An Economic Evaluation of the Barn-Finishing Method of Harvesting Hay*. Storrs Agr. Expt. Sta. Bul. 277, 1951.

Shepherd, J. B., *et. al.*, "Conservation of Nutrients and Feeding Value of Wilted Silage, Barn-Cured Hay and a Poor Quality Field Cured Hay," *Journal of Dairy Science*, 31:688-689, 1948.

Shepherd, J. B., *Experiments in Harvesting and Preserving Alfalfa for Dairy Cattle Feed*. U. S. Dept. Agr., Tech. Bul. 1079, 1954.

Slack, S. T., *et. al., Effect of Curing Methods and Stage of Maturity upon Feeding Value of Roughages*. Cornell Agr. Expt. Sta. Bul. 957, 1960.

Slack, S. T., *et. al., Effects of Chopping on Feeding Value of Hays*. Cornell Agr. Expt. Sta. Bul. 950. 1960.

observations making yield on first crop a function of calendar date.[11] The correlation coefficient value "r" of 0.8189 and $S_{y.x}$ value of ± 0.6265 was such that the function was considered acceptable for this analysis. In other words, the function was considered an adequate representation of yield response to time.

A similar analysis was performed for second-crop yields. The scatter diagrams of yield are pictured in Figure 5. The fitted first degree equation was not a good fit: a correlation coefficient of only 0.26 was obtained. This means that a linear regression equation provides an estimator of second crop yield that is not significantly more accurate than the average of the observations. For this reason, the yield of second crop was taken to be a constant 0.75 tons per acre.

The quality of first crop forage as related to time is described in Figure 6. As the date of cut advances into the season, the quality per unit decreases: for example, from 72.3 percent digestible dry matter on June 1 to 56.6 percent on July 1.[12] Second crop forage does not have as high a percentage of digestible dry matter as early cut first crop, but neither does it decrease as fast. For the purposes of this study, second crop digestibile dry matter is assumed to be the same as first crop cut on June 20.

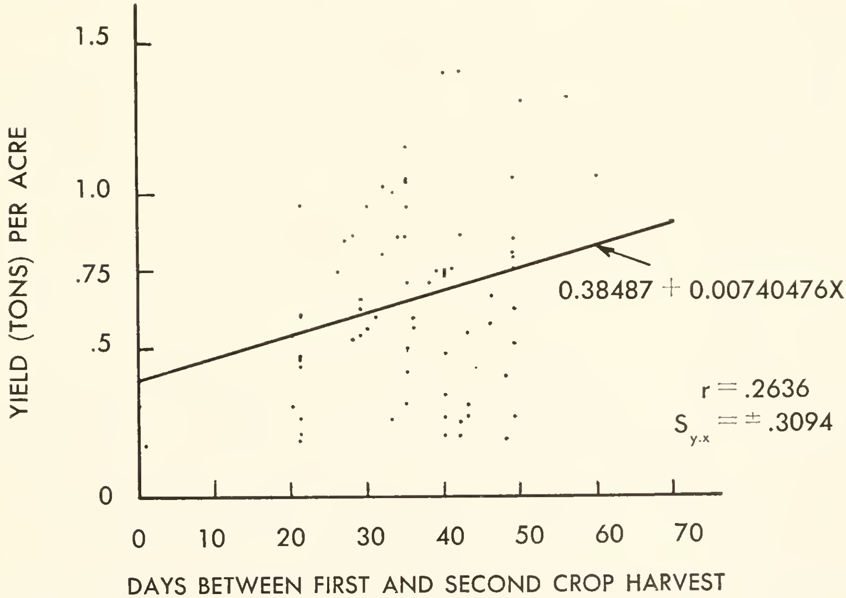

Figure 5. Yield of Second Crop Forage as it is Related to the Lapse of Time Between First and Second Crop Harvest

[11] The function is as follows: $y = a + b_x + c\,x^2$. Where: y = yield of first crop forage, x = date of cut.

[12] Reid, J. T., "Nutrition of High-Producing Cows," a paper given at the winter meeting of the N. H.-Vt. Breeding Association, 1963.

Research by Wheeler indicates that the time required to field cure forage depends upon the percentage of moisture of the forage at the time of the cut.[13] After the initial moisture has dropped to about 65 percent, 1 day less is required to field cure forage than when the initial moisture is above 65 percent.[14] Since the initial plant moisture of first crop forage steadily declines and reaches 65 percent on approximately

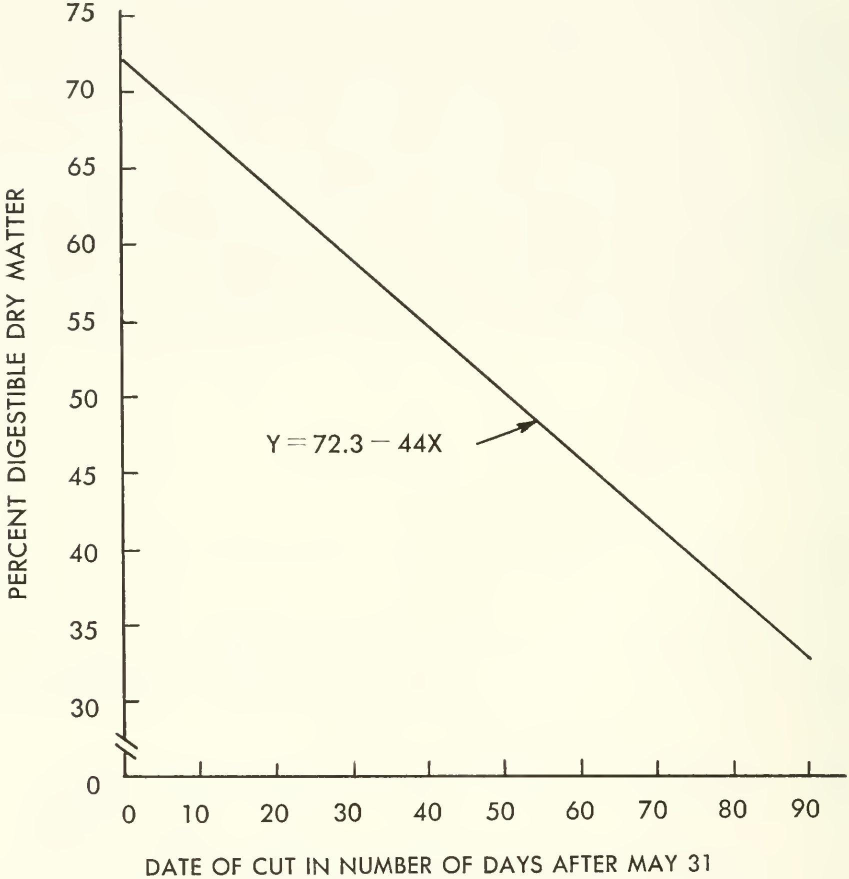

Figure 6. Relation Between Date of Cut and the Digestible Dry Matter of First Crop Forage

June 30, first crop forage can be field cured to 20 percent moisture in 1 day after June 30 if a crusher is used. Second crop forage is never field cured in 1 day to 20 percent moisture because the initial moisture never drops to 65 percent or below.

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13 Wheeler, W. C., *et. al.*, *Hay Conditioners in the Northeastern United States*, W. Va. Agr. Expt. Sta. Bul. 449, 1960.

14 Boyd, M. M., "Hay Conditioning Methods Compared," *Agricultural Engineering Journal*, 4:664-668, November 1959.

If the initial plant moisture is low when mowed: (1) the hay-in-a-day systems (using hay conditioners) do not require the drying units because the forage dries to 20 percent in 1 day, and (2) the hay-in-more-than-a-day systems will reduce the drying time required by 1 day.

Type of Forage

There were 3 types of forage considered for harvest by the model: (1) "Hay Good" — defined as forage that does not get rained on after it is mowed. This forage is fed to cows or sold if the program options allow surplus hay sales.

(2) "Hay Damaged" — defined as forage that is rained on at least 1 day but not more than 5 days after it is mowed. This forage is fed to the cows or sold if there is more than enough for feeding and the program permits selling.

(3) "Hay Salvaged" — defined as forage that is rained on more than 5 days after it is mowed. This forage is not fed to cows but is sold at a lower price than good hay or damaged hay.

Total Losses of Forage

The losses of forage in harvesting, storing, and feeding make up the total losses. Therefore, the remaining forage is available to produce milk. The harvesting losses make up the largest percentage of the total losses and depend upon the method of handling and the percentage of moisture of the forage at harvest time.[15] To control as many variables as possible, it was assumed that field-cured forage would be harvested at 20 percent moisture, and artificially dried forage would be harvested at 40 percent moisture. The total losses for first and second crops, using the 6 harvesting systems, are given in Table 1.

Weather Patterns and Date of Harvest

The weather patterns used in this study are from recorded weather observation at the official weather station in Concord, New Hampshire.[16] These observations were for the 52-year period from 1910 through 1961.

The following assumptions were made about the weather patterns and harvest operations:

(1) A rainy day was a 24-hour period starting at 5 p.m. in which more than a trace of rain falls;

(2) The operator was unable to forecast the weather; and

(3) Mowing would occur every clear day except when there were 2 mowings already cut.

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[15] Slack, *et. al., Effect of Curing Methods and Stage of Maturity upon Feeding Value of Roughages,* Cornell Agr. Expt. Sta. Bul. 957, 1960.

[16] *Local Climatological Data with Comparative Data,* Concord, New Hampshire, U. S. Department of Commerce, Weather Bureau, 1910 through 1961.

The number of days that rain occurs during the first crop and the quantity of rainfall affects the starting date of the second crop. If there are many days of rain, harvest of second crop will be delayed due to the limitation of the harvesting system to handle the quantity of forage. On the other hand, if rainfall is abundant during first crop harvest, the aftermath grows faster than otherwise, and the second crop can be mowed and harvested sooner. Conversely, less rainfall during first crop means a longer growth period for aftermath, and the length of time between the mowing of first and second crops is lengthened.

These were 3 starting dates used for each weather pattern: June 1, 15, and 30. These dates represent early, medium, and late-cut forage, respectively.

Labor and Machinery Requirements

In determining the labor and machinery requirements and input-output relations, labor was assumed to be used at all times in conjunction with equipment; i.e., when a man was working, he was using some

Table 1. Total percentage losses of first and second crop forages by various harvesting methods*

Method	Percentage of total crop lost					
	Forage Rained on 1–5 days		Forage Rained on 5 plus days		Forage not rained on	
	1st cutting	2nd cutting	1st cutting	2nd cutting	1st cutting	2nd cutting
	Percent	Percent	Percent	Percent	Percent	Percent
Field cured	33.6	32.6	40.0	40.0	20.1	19.1
Crushed field cured	31.6	30.6	40.0	40.0	18.1	17.1
Crushed barn dried without heat	......	......	......	......	14.8	12.8
Crushed wagon dried with heat	......	......	......	......	14.8	12.8
Flail cut flail harvest	......	......	......	......	21.4	19.4
Wilted grass silage	......	......	......	......	19.5	19.4

* These losses were determined statistically from many experiments reported in bulletins, 2 of which are: Ross, V. E., and Fellows, I. F., *An Economic Evaluation of the Barn-Finishing Method of Harvesting Hay*, Storrs Agr. Expt. Sta. Bul. 227, 1951; and Trimberger, G. W., *et al.*, *Effect of Curing Methods and Stage of Maturity upon Feeding Values of Roughages*, Cornell Agr. Expt. Sta. Bul. 910, 1955.

piece of equipment. Hence, labor and machinery hours were the same. The requirements were based on an acre of land where the independent variable was yield per acre. The base unit of account for input-output coefficients was 1 acre. Coefficients varied with yield per acre.

Labor was available each day in fixed amounts for all harvesting. No labor in addition to the regular work force was hired.

With the exception of the flail system, the data used to determine the labor and machinery requirements on the farm, presented in Figures 7 and 8, were obtained from 1 source.[17] The coefficients for the flail system were developed from data from many sources.[18]

The hours of labor and machinery inputs per acre of cropland were determined as yield varies for each of the 6 harvesting systems from Figures 7 and 8. For example, solving the formula in Figure 7 indicates that if the yield is 3 tons per acre, 3.4 hours of labor and machinery are required to mow, harvest, and store the forage from 1 acre of cropland using the system "field-cured baled", and 4.1 hours are required for the systems "crushed barn dried without heat" and "crushed field cured".

Equipment Capacities

For each harvesting system a maximum number of acres and tons of forage that could be mowed in a day were specified. These limits were the capacities of the systems that could change as the limiting factor was eliminated. For example, the limiting factor in the wagon-dried system was the capacity of the drier, but after the initial moisture fell below some percentage, the drier was not used and the ton limit was consequently increased.

The number of acres that could be mowed and harvested per day by each system depended upon the yield per acre. The assumption that a total of 16 hours of labor were available per day limited the number of acres that could be mowed and harvested per day. From this assumption and the labor requirements developed previously, maximum acreages that could be mowed and harvested per day were established. Since yield varies, the relation was developed in functional form for use in the model. These functions are shown in Figures 9, 10, and 11. The maximum number of acres that could be mowed, harvested, and stored in 1 day for any system is 6 — the physical capacity of the resources due to time required to travel over the land, independent of yield.

The maximum tons that a system could handle per day also depended upon the capacity of the slowest part of the operation. For example, the capacity of the heat drying unit for the "crushed, wagon dried with heat" system limited the system capacity to 8 tons per day when the drier was used.[19] Therefore, the series of functions in Figures 9, 10,

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[17] *Agricultural Planning Data for the Northeastern United States*, Pennsylvania State University, A. E. and R. S. 51, July 1965.

[18] Two examples are: Wheeler, W. C., *et. al., Hay Conditioners in the Northeastern United States*, W. Va. Agr. Expt. Sta. Bul. 449, 1960, and Phillips, Ross A., and Elliot, Kendall C., *Using Flail Forage Harvesters*, W. Va. Agr. Expt. Sta. Bul. 474, 1962.

[19] *Hay Drying*, Farm Department of Central Vermont Public Service Corporation and New Hampshire Farm Electric Utilization Council, Spring, 1963.

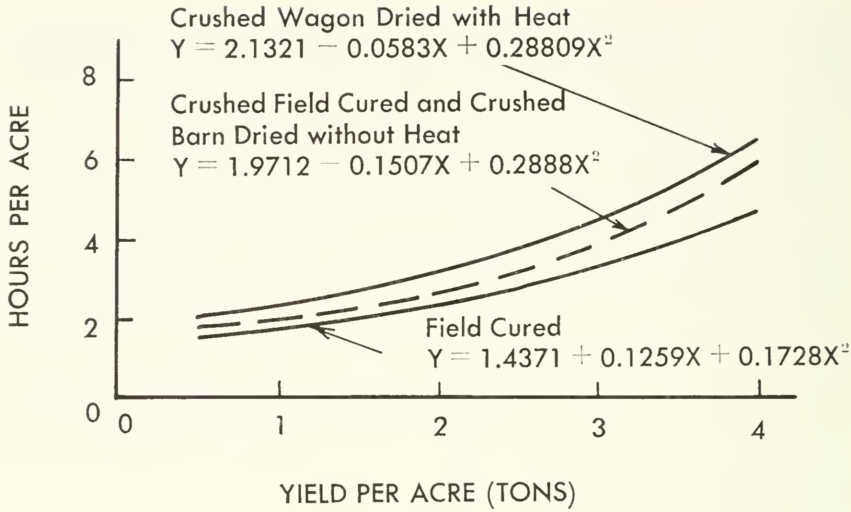

Figure 7. Machinery and Labor Requirements Per Acre as Yield Varies for Selected Systems of Harvesting

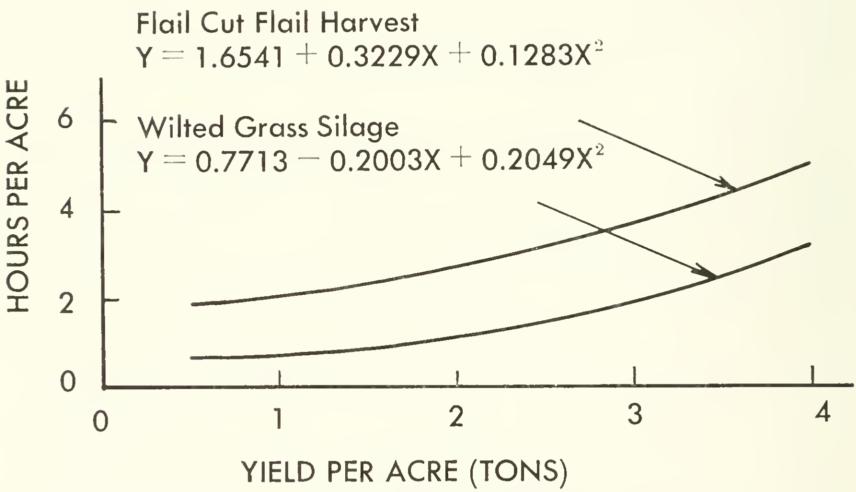

Figure 8. Machinery and Labor Requirements Per Acre as Yield Varies for Selected Systems of Harvesting

and 11 represent the maximum number of acres and tons of forage that could be mowed, harvested, and stored per day. The maximum 1 day workload is to (a) mow and harvest a given number of acres, or (b) to harvest and store 2 mowings. A yield of less than 0.5 tons per acre was not harvested because it was assumed to be an uneconomical alternative.

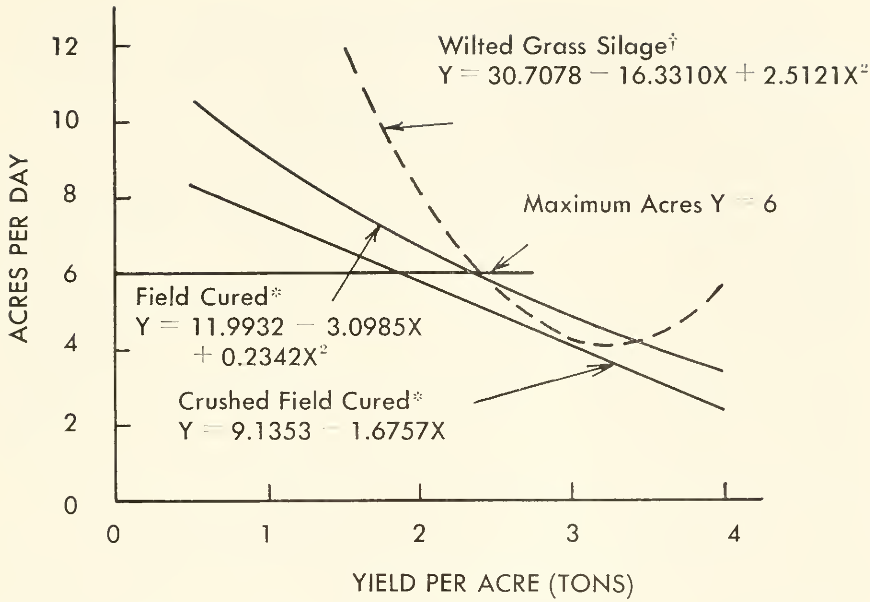

Figure 9. Number of Acres That Can Be Mowed Per Day as Yield Varies for Selected Systems of Harvesting

Labor Requirements for Cows

The labor requirements for cows on a dairy farm vary with the method of milking and the type of forage fed. In this study the cows were assumed to be milked in stanchions. There were 3 types of forage harvested: baled hay, chopped hay, and haycrop silage. Therefore, there are three different functions describing the labor requirements for the cows (Table 2). Much of the labor required for a herd of cows is fixed. Therefore, as the size of the herd increases, the average time per cow decreases.

Harvesting Equipment Investment and Annual Costs

The equipment used by the base system included a 7-foot mower; a 2-plow tractor; a 3-plow tractor; a side-delivery rake; a 32-foot elevator; a baler with bale thrower; and 3 wagons. In addition to the basic equipment, the "crushed barn-dried without heat" system had a

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* These functions are obtained by dividing the yield into total crew hours per day. In this case the crew hours per day are 16.

† The 6 acre maximum and this function are the limits. The acres per day 1st crop for this system is limited by the 6 acre maximum and this function, while for 2nd crop the limits are the same as for crushed field cured baled.

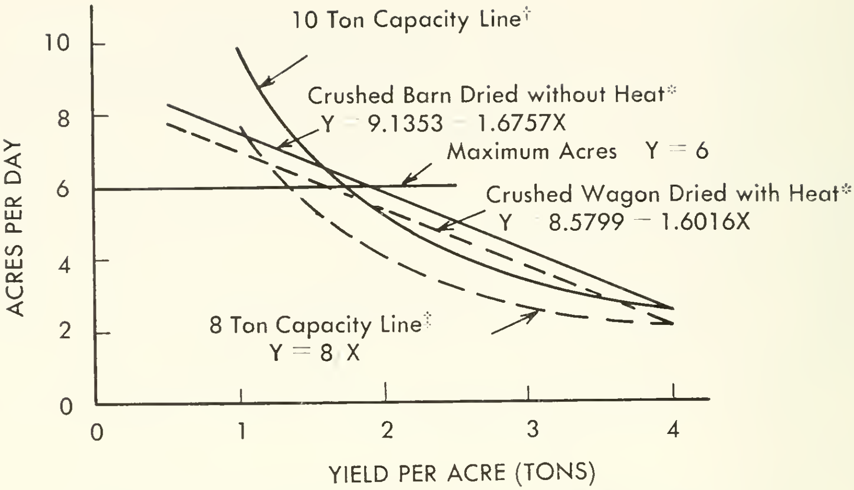

Figure 10. Number of Acres That Can Be Mowed Per Day as Yield Varies for Selected Systems of Harvesting

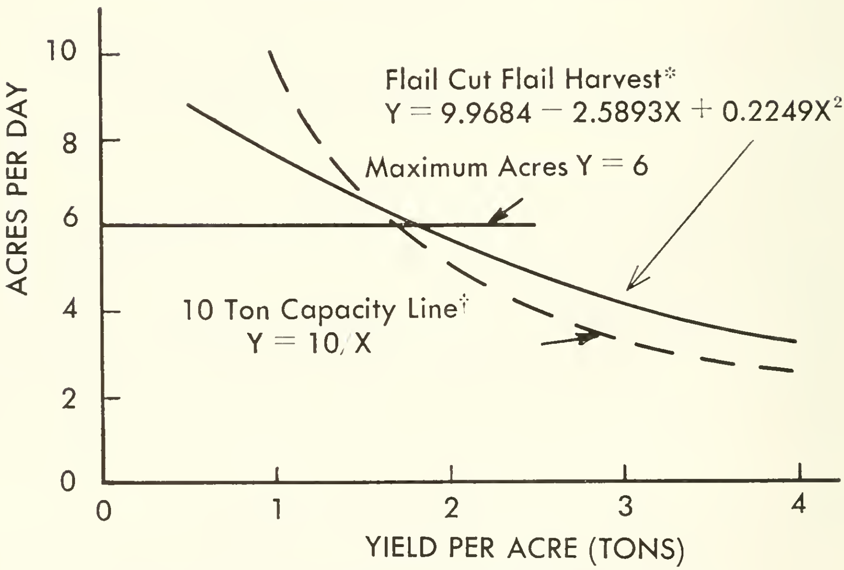

Figure 11. Number of Acres That Can Be Mowed Per Day as Yield Varies for Selected Systems of Harvesting

* These functions are obtained by dividing the yield into total crew hours per day. In this case the crew hours per day is 16.

† This is the non-heat drier capacity per day. The line is determined by dividing yield per acre into 10.

‡ This is the heat drier capacity per day. The line is determined by dividing yield per acre into 8.

Table 2. Daily milk cow labor requirements with three types of forage when milking is done in stanchions

Operation	Haycrop silage		Baled hay		Chopped hay	
	Fixed	Variable	Fixed	Variable	Fixed	Variable
	Hours	Hours	Hours	Hours	Hours	Hours
2 Single milking units	0.093	0.103	0.093	0.103	0.093	0.103
Cleaning	0.733	....	0.733		0.733	
Hay feeding	0.210	0.005	0.210	0.005	0.146	0.005
Silage feeding	0.200	0.009	....	....	....	....
Grain feeding	0.142	0.005	0.142	0.005	0.142	0.005
Manure handling	–.073	....	–.073		–.073	
Bedding	0.154	0.005	0.154	0.005	0.154	0.005
Other	0.078	0.009	0.078	0.009	0.078	0.009
Miscellaneous	0.137	......	0.137	....	0.137	......
Total	1.674	0.136	1.474	0.127	1.410	0.127

crusher, 5-HP motor and 36-inch fan, and duct work in the barn; and the "crushed field-cured" system had a crusher.

There are 2 different types of harvesting operations represented by these 6 harvesting systems. Type I relied entirely upon field curing and required more than one day for the forage to dry to a moisture content in order to safely store it. The "crushed field-cured" system required 2 days, including the day of mowing to harvest. The field cured system required 3 days, including the day of mowing. The Type II system, "crushed, barn dried without heat," is a hay-in-a-day system, i.e., the forage was harvested the day it is mowed.

Table 3. Investment and costs for six forage harvesting systems

System	Total Investment	Fixed cost per year	Variable cost per hour	Variable cost per hour to artifically dry forage
	Dollars	Dollars	Dollars	Dollars
Field cured	11,010	2,077.55	4.70	0.0
Crushed field cured	11,860	2,253.00	5.13	0.0
Crushed barn dried without heat	13,410	2,574.10	5.13	0.125
Crushed wagon dried with heat	23,910	4,940.95	5.13	0.778
Flail cut flail harvest	13,220	2,145.50	4.13	0.125
Wilted grass silage	16,545	3,039.46	4.75	0.0

The cost, investment, and price data used were those prepared for use by the Northeast Dairy Adjustment Study Group.[20] Tables 3 and 4 summarize the cost, price, and investment requirements for each system.

Milk Production

Because the development of the milk production surface for an individual cow or herd of cows is a complex operation, the variables used are described in some detail.

The general form of the milk production function was defined as:

$$MP = f(F, G, L, A, M, X_1 \ldots X_n) \qquad (1)$$

where MP refers to milk production in a specific period; F refers to forage (quality and quantity considered); G refers to grain; L refers to the stage of lactation; A refers to the ability of the cow to produce milk; M refers to the dairy herd management; and $X_1 \ldots X_n$ refers to other unspecified factors.

To assure that the major objectives of this study would be accomplished, i.e., to evaluate the organization of forage harvesting systems and grain feeding alternatives, the only variables that were allowed to vary were forage (F) and grain (G). Therefore, equation (1) becomes:

$$MP = f(F, G/L, A, M, X_1 \ldots X_n) \qquad (2)$$

The / notation indicates that forage (F) and grain (G) are allowed to vary while lactation (L), ability (A), management (M) and other factors ($X_1 \ldots X_n$) are held constant.

Equation 2 states that milk production is a function of feed inputs and that everything else is held constant at some level. Therefore.

Table 4. Cost or price per unit of resources used and products produced

Resource or product	Dollars
Annual fixed cost per cow	100.00
Investment per cow	350.00
Price per ton of hay to sell	26.10
Building investment per cow	585.00
Price of labor per hour	1.13
Price of grain per ton	79.80
Price of milk per cwt.	5.46
Price of hay salvaged to sell per ton	20.00
Price of hay to buy per ton	35.30
Building fixed cost per thousand	159.83

[20] *Agricultural Planning Data for the Northeastern United States, op. cit.*

any change in the quality or quantity of the feed will result in a change in the milk produced per unit of time. The milk production function for the purposes of this study is a herd function. It was assumed that the herd composition is homogeneous and that changes in feed inputs can be reflected in output for the herd much as they would be for the individual cow. The assumptions used in this study to control the non-feed and feed factors are outlined in the following sections.

Cow Ability

The ability of a cow or a herd of cows to convert the combinations of forage and grain into milk is determined by 2 closely related factors: (1) the inherent milk producing ability of the cow and (2) the ability of the cow to consume large quantities of forage. To overcome variations that occur between cows, it was assumed that all cows had a high inherent ability and could consume large amounts of forage.

Stage of Lactation

The freshing pattern of a herd of dairy cows has a great influence upon the seasonal milk produced; therefore, the assumption was made that the freshing pattern was randomly distributed throughout the year and that any cows added to the herd would not disturb this distribution.

Other Factors

There are many other factors that affect the quantity of milk produced by a cow or a herd of cows such as cow age, body weight, and temperature. In this study it was assumed that body weight did not change. This implied that (1) the total amounts of nutrients consumed by the cow would be used in the production of milk, and (2) that the age of the cows was randomly distributed. The same number of cows, therefore, would be replaced every year; thus, the milk production surface was not affected. Further, it was assumed that all other variables, such as cow temperatures, were constant.

Forage Input

Forage is the major input in the production of milk; therefore, a complete understanding of the meaning of forage as used in this study is necessary. It should be understood that quality and quantity of forage produced per acre by date of cut are inversely related.

In addition to the quality and quantity relation, nutrients are lost through rain damage; thus, there are 2 types of forage available to produce milk: (1) forage undamaged by rain and (2) forage damaged by rain. The difference between the 2 types of forage is that for each and every date of cut, the percentage of digestible dry matter of rain-damaged forage will be less than if no rain damage occurred. When rain-damaged forage is fed, nutrient intake will drop unless more forage is consumed or grain consumption is increased.

Other factors associated with both types of forage are: (1) the feed acceptance level of the cow by date of cut of forage and (2) the minimum amount of forage that will be consumed per cow per day.

The feed acceptance level of the cow is the combination of forage and grain that she will consume per day, and depends upon the date of cut and whether the forage was rain damaged or not. The acceptance level reflects the quality of the forage by date of cut and weather damage.

There is an acceptance level for each type of forage (rain damage or no rain damage) by date of cut. Further, a minimum amount of forage will be consumed per cow per day, independent of the type or date of cut.

Grain Input

Grain is the second major input used in the production of milk. Purchased grain is not as variable in quality as forage. Therefore, the quality of the grain fed was held constant, while the quantity was allowed to vary. These methods were considered: (1) grain constant; (2) milk constant; and (3) constant milk-grain ratio. This means that 3 comparisons were made, 1 for each type of grain feeding management. These 3 methods outline the extreme ways that milk can be produced using forage and grain as variables.

Using the grain-constant method of producing milk, grain was held constant at a fixed number of pounds per cow per day. Forage was fed free choice. Milk production per cow per day varied according to the amount of nutrients supplied by the fixed quantity of grain and the free-choice quantity of forage consumed.

Using the milk constant method, milk was held constant at a fixed number of pounds per cow per day. The nutrients required to produce this milk had to be supplied by the forage and grain consumed.

The milk-grain ratio type of management is very commonly used by farmers, and implies that cows will be fed 1 pound of grain for fixed amounts of milk produced. Forage is fed free choice. Less forage is consumed as the date of cut advances; therefore, less nutrients from forage are consumed by the cow. As a result, milk production declines, and the amount of grain fed declines. This becomes a cycle in that: (1) late cut forage is not as palatable as early cut forage and has less digestible dry matter per unit; thus (2) milk production declines because only nutrients consumed are used to produce milk; therefore, (3) less grain is fed, because it is fed according to the amount of milk produced.

The Milk Production Surfaces

It was necessary to use 2 production surfaces to describe the relations developed from the available data because of the 2 types of forage,

i.e., no rain damage and rain damage.[21] The difference in the nutrient value of these forages is reflected in research by Rakes, et. al.[22] They found that the digestible dry matter was reduced about 5.3 percent and the voluntary intake about 17.4 percent when forage was rained on as compared to no rain damaged forage. The production surfaces are shown in Figures 12A and 13A, where Figure 12A represents the daily milk production surface using no rain damaged forage and grain and Figure 13A represents the daily milk production surface using rain damaged forage and grain. Figure 12A needs to be explained since the only difference is the type of forage fed; Figure 13 is self-evident.

The X and Y axes in Figure 12A represent the pounds of grain and forage available for consumption per cow per day, respectively. The isoquants represent the expected daily milk output per cow resulting from the various combinations of inputs (forage and grain).

There are 2 sets of isoquants. The solid and broken isoquants represent the milk output per cow per day that can be expected using the combinations of early cut and late cut forage and grain, June 1 and July 10, respectively. The difference in the isoquants reflects the results expressed by Slack, *et. al.*, "approximately 20 percent more late-cut forage must be eaten to provide the same amount of digestible dry matter."[23]

The acceptance level lines represent the combinations of forage and grain that the cow will consume per day, if the forage is fed free choice and grain is regulated by date of cut of the forage. The highest feed acceptance level is for June 1 forage and the lowest for July 10. The 2 lines converge at 13.6 pounds of forage and 22 pounds of grain. This convergence occurs because the cow will eat a minimum quantity (13.6 pounds) of any type and quality of forage and a maximum quantity (22 pounds) of grain.

There are 2 observations inherent in this analysis. First, the 2 sets of isoquants become identical if time is considered a variable, *i.e.*, June 1 isoquants become July 10 isoquants. This should be obvious, since there is a milk production surface for each date of cut represented only by June 1 and July 10. Second, the feed acceptance level lines become identical if time is considered a variable. As date of cut advances, the amount of forage that the cow will consume will decline such that when date of cut is July 10, the combinations of forage and grain consumed is expressed by the July 10 acceptance level line. The lowest isoquant in Figure 12A represents those combinations of early cut forage and grain that will produce 25 pounds of milk per cow per day. A possible feed combination may be 3 pounds of grain and 26.8 pounds of forage. If 3

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[21] Data were obtained from many sources. For a representative sample, see: Slack, E. T., *et. al., Effect of Chopping on Feeding Value of Hays*, Cornell Agr. Expt. Sta. Bul. 950, 1960, and Loosli, J. K., *et. al.*, "The Comparative Value of Ladino Clover. Birdsfoot Trefoil, Timothy and Alfalfa Hays for Yield and Quality of Milk," *Journal of Dairy Science*, 33:228-236.

[22] Rakes, A. H., *et. al., The Feeding Value for Milk Production of Hays Cut at Various Dates,* W. Va. Agr. Expt. Current Rpt. 35.

[23] Slack, S. T., et. al., *Effect of Curing Methods and Stage of Maturity upon Feeding Value of Roughages,* Cornell Agr. Expt. Bul. 957, 1960, P. 24.

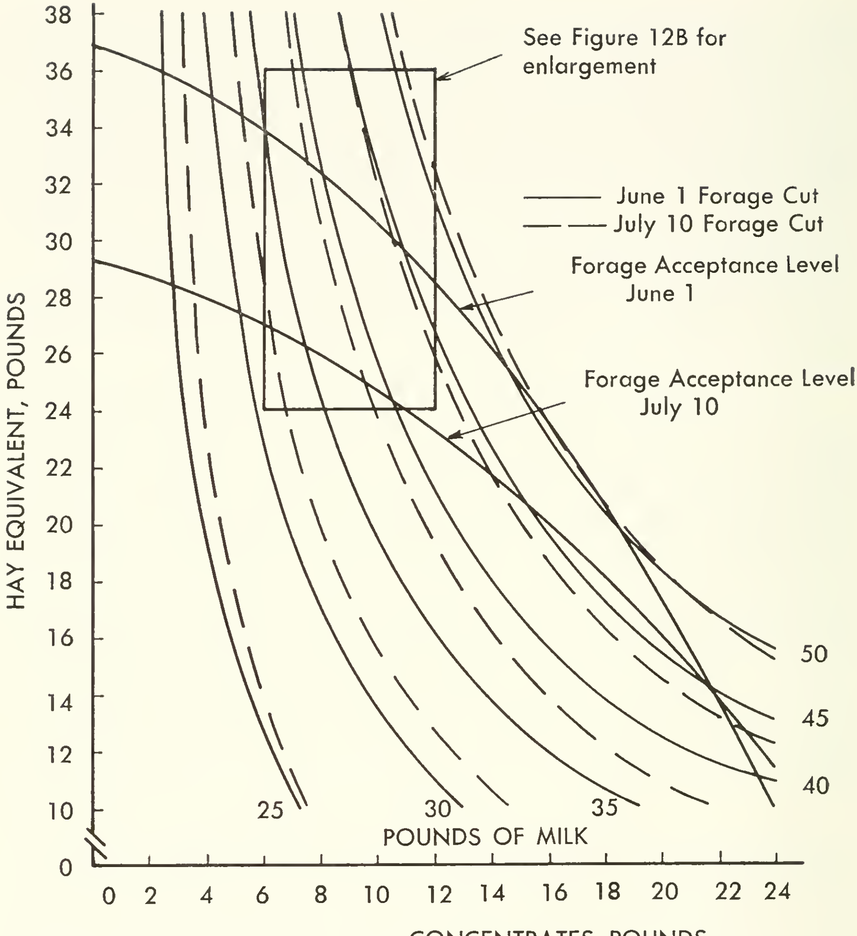

Figure 12A. Estimated Daily Milk Isoquants, No Rain Damaged Forage, and Two Dates of Cut

additional pounds of grain are used, 25 pounds of milk can be produced with the 6 pounds of grain and only 12.3 pounds of forage.

To increase milk production, using only the June 1 isoquants, increasing quantities of forage and grain may be fed, or 1 input may be held constant and the other increased. For example, shifting from the 25- to the 30-pound isoquant can be accomplished by holding forage constant at 26.8 pound level and increasing grain from 3 to 5.3 pounds. Shifting to still higher levels of milk production can be accomplished by increasing grain feeding and holding forage constant, increasing forage with grain held constant, or by increasing both hay and grain feeding. In all instances, the acceptance level for the date of cut and the minimum forage line describes the outer limits of hay and

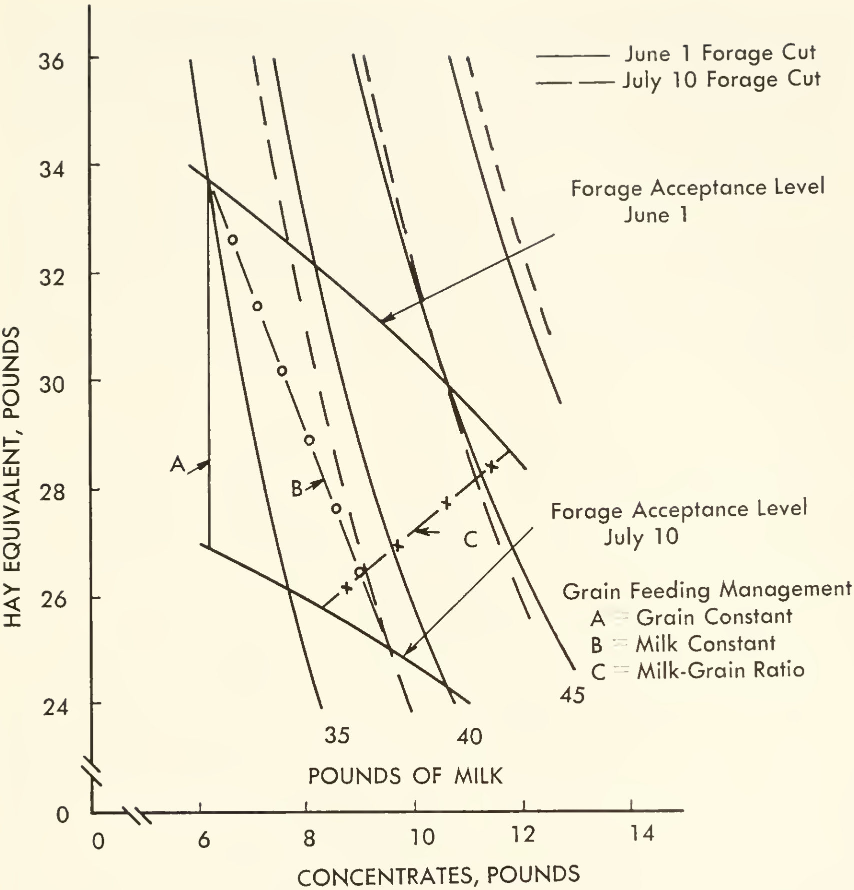

Figure 12B. Estimated Daily Milk Isoquants, No Rain Damaged Forage, Two Dates of Cut and Three Methods of Grain Feeding

grain consumption. Thus, the quantity of milk produced per cow per day can be determined for the different qualities and quantities of forage and grain.

Figure 12B is an enlargement of the outlined rectangular section of Figure 12A. This is the section of the isoquants and acceptance lines used to determine the functions that represent the 3 management methods of feeding grain in the production of milk, *i.e.*, grain constant, milk constant, and constant in milk-grain ratio. The X and Y axes, forage acceptance lines, and isoquants in Figure 12B are represented in the same manner as in Figure 12A, while lines A, B, and C are the functions that represent the management methods of feeding grain, grain constant, milk constant, and milk-grain ratio, respectively. Implied in this Figure 12B, as in Figure 12A, is that forage acceptance line June 1 moves down and becomes forage acceptance line July 10, and the June 1 isoquants

move up and to the right and become July 10 isoquants. Therefore, the intersection of the isoquants and acceptance lines for the same date of cut represents the combinations of forage and grain to produce the different quantities of milk. For example, if milk output is held constant at 35 pounds per cow per day, forage and grain consumption by date of cut will range from 33.7 and 6.3 pounds per day to 24.9 and 9.6 pounds per day, respectively.

The following functions represent lines A, B, and C in Figures 12B and 13B, *i.e.*, these functions represent the forage and grain consumed and milk produced by date of cut for the 3 grain feeding management methods with undamaged forage and rain damaged forage. In these functions F refers to forage, G refers to grain, T refers to date of cut, and M refers to milk produced. All of the inputs and outputs are in pounds per cow per day.

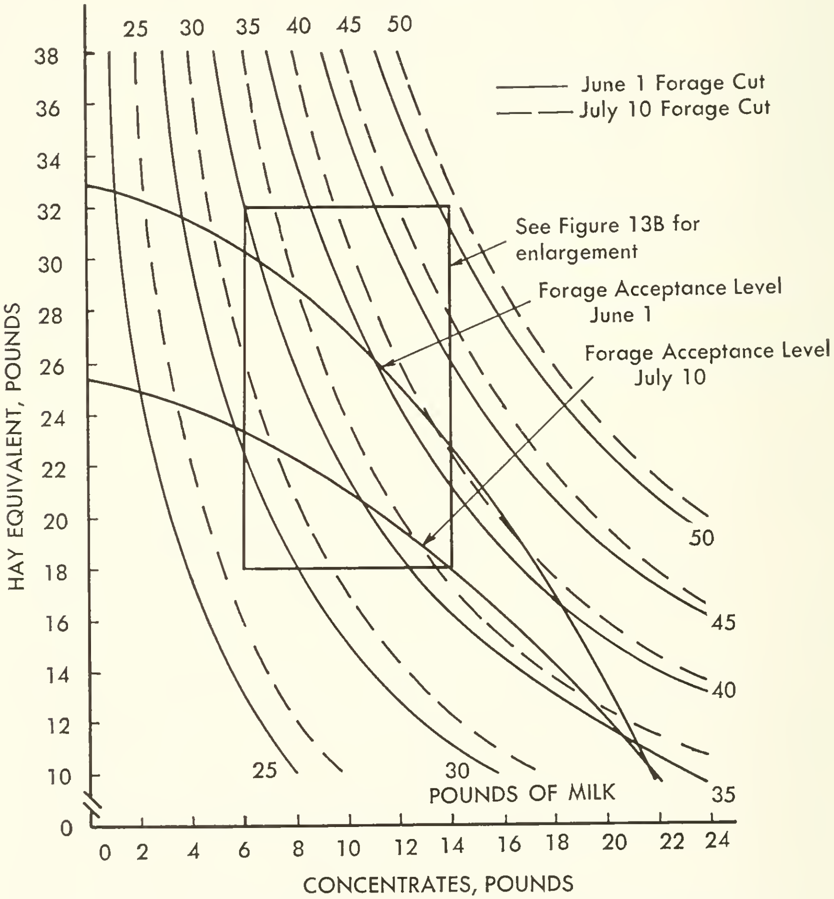

Figure 13A. Estimated Daily Milk Isoquants, Rain Damaged Forage, Two Dates of Cut

No Rain Damaged Forage Functions (Figure 12B)

A. Grain Constant (6.3)

$F = 33.7743 - 0.1743\ (T)$

$M = 9.5716 + 0.7568\ (F)$

B. Milk Constant (35.0)

$F = 33.7743 - 0.2217\ (T)$

$G = 6.2154 + 0.0846\ (T)$

C. Milk-Grain Ratio (4:1)

$F = 28.6205 - 0.0705\ (T)$

$M = -86.9157 + 4.6178\ (F)$

$G = M/4$

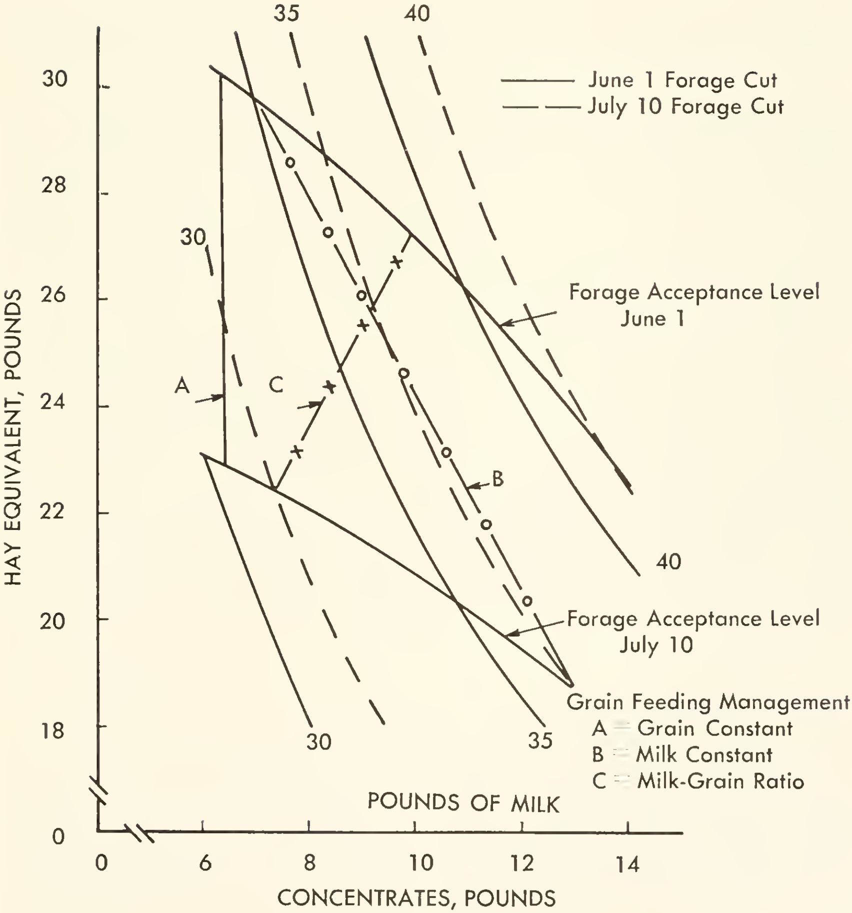

Figure 13B. Estimated Daily Milk Isoquants, Rain Damaged Forage, Two Dates of Cut and Three Methods of Grain Feeding

Rain Damaged Forage Functions (Figure 13B)

A. Grain Constant (6.3)
$F = 30.3358 - 0.1858\ (T)$
$M = 1.0890 + 0.7769\ (F)$

B. Milk Constant (35.0)
$F = 29.9294 - 0.2794\ (T)$
$G = 6.6449 + 0.1551\ (T)$

C. Milk-Grain Ratio (4:1)
$F = 27.4294 - 0.1294\ (T)$
$M = -7.4357 + 1.6938\ (F)$
$G = M/4$

EVALUATION OF ALTERNATIVES WITH SIMULATION MODELS

The situations that can be analyzed using simulation analysis are numerous. Different research questions can be answered by: (1) changing production functions within the model, such as a forage yield response; or (2) adding an alternative machinery system or a weather pattern sequence. The number of obtainable solutions of the simulation model is the product of the number of alternatives included. The initial design for this analysis was to appraise: 6 forage harvesting systems, 52 weather patterns, 3 forage harvest starting dates, 3 grain feeding systems, and 3 sizes of herd.

All combinations of these options would have required 8,424 solutions. This would have created a data summarization problem, which raised a question as to the necessity for computation of all the possible problem combinations. The machine computation, therefore, was divided into 2 phases. Phase I analysis was designed to evaluate grain feeding methods and machine harvest systems to select the most profitable combinations. Phase II analyisis was designed to study variations in forage balance (purchases or sales) and in income as influenced by 52 weather patterns for 2 harvest systems, 3 dates of cut, and 3 herd sizes.

Phase I Analysis

Phase I included combinations of 6 forage harvesting systems, 3 dates of cut, 3 grain feeding systems, 3 herd sizes, and 3 weather patterns. A total of only 486 solutions were possible. The 3 weather patterns were selected from 52 years of records from 1910 through 1961 to represent "average," "wet," and "dry" rainfall-clear day weather relations. Acreage of hayland was set at 100 acres. Herd size was set at 3 levels — 75 cows, 100 cows, and allowed to vary so as to consume all the eatable forage produced.

Most Profitable Grain Feeding Method

The 3 grain feeding methods included feeding grain to each cow at a ratio of 1 pound of grain to 4 pounds of milk, feeding a fixed quantity of grain to each cow, and feeding grain and forage in the proportions needed to obtain a fixed quantity of milk.

The Phase I analysis indicated that feeding each cow the same quantity of grain is an uneconomic method. Although as many cows could be fed as with the other grain feeding methods, net farm income was lower than with the other 2 grain feeding methods. This result is compatible with the long standing recommendations of many nutrition specialists for feeding cows according to milk production.

Difficulties, mainly stemming from inadequacy of data, were encountered in the analysis with feeding grain to maintain constant milk output. Net income became progressively larger as the date of cut advanced. The feeding trials that the milk production functions were based upon were not designed to measure the substitution rate of grain for quality of hay. Due to inadequate data further analysis of this feeding method was considered beyond the scope of this study.

The Phase I analysis, therefore, indicated that feeding according to a milk-grain ratio would be of most value for further study in Phase II.

Most Profitable Forage Harvest Systems

The five forage harvesting systems analyzed were: field cured and baled: crushed, field cured and baled; crushed, baled and barn dried without heat; crushed, baled and wagon dried with heat; and flail cut, flail harvested and barn dried without heat.

Crushed, baled, and wagon dried with heat was economically inferior to the other systems, and this result is compatible with farmers' experience with this system of forage harvesting.

Although the flail cut, flail harvest system is particularly well suited for small farms, it is not commonly used by farmers. The speed of harvest may not be as rapid as many large farmers desire. However, Phase I of the analysis showed the flail cut, flail harvest system to be 1 of the more profitable systems. Its performance in terms of income was about equal to the systems of harvest in which the hay was crushed, baled, barn dried without heat. Preference of one of these systems over the other would be based upon considerations or features not considered in the simulation model.

Crushing hay after mowing for quick drying generally cuts 1 day off curing time. The addition of the crushing operation appreciably increased income for June 1 and June 15 cut hay in all cases. For June 30 cut hay the advantage of the crusher in the system generally was not as great, and under several situations was of no advantage in the harvesting systems. From the analysis using three weather patterns, it can be concluded that the crusher offers advantages in the early cut hay operations.[24]

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[24] For more detailed information on the 5 forage systems and the 3 grain feeding systems, see Cloud, *Op. Cit.*

Based on the Phase I analysis of the 6 machinery systems, the number of systems was reduced from 6 to 2 for study in Phase II. The 2 systems selected were: crushed, field cured, and baled; and crushed, baled, barn dried without heat. These are the more common systems found on farms.

Phase II Analysis

Phase II of the analysis was designed to include combinations of the 2 most profitable harvest systems, the most profitable grain feeding system, 3 harvest starting dates, 3 cow number options, and 52 weather patterns.

The 2 forage harvesting systems were: crushed, field cured. and baled; and, crushed, baled, and barn dried without heat. The grain feeding method was the milk-grain ratio of 1 pound of grain to 4 pounds of milk. The 3 starting dates of harvest were June 1, 15, and 30. The 52 weather patterns were those of the period from 1910 through 1961. Variations in intensity of land use and consequent sales and purchases of hay were represented by 3 herd sizes on the 100 acres of cropland.[25] The 3 herd sizes studied were 75 cows, 100 cows (both with hay purchase or sales allowed), and cows varying according to the number needed to consume the harvested forage. None of these situations reflect an actual course of action taken by farmers with respect to ratio of cows to cropland because farmers tend to cull their herd a little heavier when feed supplies are short. It is doubtful if a dairyman could buy and sell enough animals of the desired quality to obtain the degree of variability in herd size assumed when cow numbers are permitted to vary in response to forage supply. These 3 situations tend to bracket the alternatives within which dairymen operate.

Influence of Date of Cut and Weather Pattern on Forage Balance

75 Cows and Selected Hay Harvesting Systems

The influence of hay purchases and sales on farm income is important in the analysis because of the many and varied problems involved under actual operating conditions over time. Usually when one farm is short on hay, other farms are also short on hay, and relatively higher prices for hay purchases prevail. When hay supplies are plentiful on the individual farm, this usually means that all farms have plenty of hay and relatively lower prices prevail. Many farmers alleviate the

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[25] Harrington, D. H., Andrews, R. A., "*Net Incomes and Resources Valuations of Optimum Organizations for Dairy Farms in Northern New England,*" Agr. Expt. Sta. Bul. 490, 1967.

problem by establishment of a "hay bank." Essentially, this is carrying inventories from years of abundant supply over to years of short supply.

The intensity of cropland use with 75 cows was at a level of 1.5 acres providing the hay for 1 cow. At this level of intensity little hay was bought or sold when date of cut was June 1.[26] As date of cut advanced, greater quantities of hay sales were made. With date of cut advanced to June 30, sizable quantities of hay were sold. The extent of and variation in hay purchases or hay sales in 52 weather patterns for harvesting hay are shown in Table 5.

100 Cows and Selected Hay Harvesting Systems

This ratio of cows to cropland represented a rather intensive use of cropland and the operations were essentially based upon some hay purchases occuring as early as the June 15 date of cut. With a June 1 date of cut, sizable quantities of hay were purchased at assumed prices. Hay purchases or sales for this size option are shown in Table 5.

Number of Cows Varying and Selected Hay Harvesting Systems

The herd size under this situation was allowed to vary to the extent that all eatable forage produced on the 100 acres was fed to dairy cows. This assumed that the farmer is able to buy and sell dairy cows in the market each year to vary his herd size. It also assumed that the complementary farm production resources are available. The particular advantage of this situation lies in eliminating problems with the pricing of hay, and hence, in concentrating the full influence of date of cut on net farm income in terms of feeding quality.

Under this situation there were no hay purchases but only sales of small quantities of hay that was beyond use as feed due to rain damage.

Influence of Date of Cut and Weather Pattern on Gross Farm Income

75 Cows and Selected Hay Harvesting Systems

Gross farm income declined as date of cut advanced for both harvest systems. The distribution of gross income by date of cut for the 52 weather patterns with the crushed, field cured, and baled system is shown in Table 6. The distribution for the crushed, baled, barn dried

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[26] The option of purchasing and selling hay presents at least 2 analytical problems. The first involves estimating prices paid and prices received. The second involves assumptions about variations in quality of purchased forage. To reflect marketing services performed such as transportation and commission costs on sales, the purchased price for hay was established at a higher level than the sales price. These prices reflect what the farmer would receive or pay for hay at the farm storage point of sale. Purchased hay was assumed to be of the quality obtained by cutting on June 30. This seemed to be a realistic assumption in light of actual quality of hay exchanged in the hay market.

Table 5. Percentage of Times During Weather Patterns, 1910-1961, that Specified Number of Tons of Hay Would Have Been Bought or Sold, by Starting Date of Cut

Size of Herd, Hay Harvest System, and Starting Date of Cut	Tons of Hay Sold								No Hay Sold or Bought	Tons of Hay Bought						
	100+	75–99	50–74	40–49	30–39	20–29	10–19	1–9	0	1–9	10–19	20–29	30–39	40–49	50–74	75–99
									(Percent)							
75 Cows; Hay Crushed, Field Cured and Baled:																
June 1				2		4	2	17	2	23	27	19	4			
June 15		2	29	19	29	19	2									
June 30	13	62	25													
75 Cows; Hay Crushed, Baled and Barn Dried:																
June 1			2		6	10	21	29	6	19	7					
June 15		21	79													
June 30		100														
100 Cows; Hay Crushed, Field Cured and Baled:																
June 1											2			6	33	59
June 15							2	4		12	17	27	19	17	2	
June 30			6	19	28	27	12	6			2					
100 Cows; Hay Crushed, Baled Barn Dried:																
June 1											2		6	10	63	19
June 15						10	12	13	6	38	21					
June 30	2	2	48	40	8											

Table 6. Percentage of Times During Weather Patterns, 1910-1961, That Specified Gross Farm Income Would Have Been Obtained, by Starting Date of Cut

Size of Herd, Hay Harvest System, and Starting Date of Cut	Thousands of Dollars																																		
	27.5–27.9	28.0–28.4	28.5–28.9	29.0–29.4	29.5–29.9	30.0–30.4	30.5–30.9	31.0–31.4	31.5–31.9	32.0–32.4	32.5–32.9	33.0–33.4	33.5–33.9	34.0–34.4	34.5–34.9	35.0–35.4	35.5–35.9	36.0–36.4	36.5–36.9	37.0–37.4	37.5–37.9	38.0–38.4	38.5–38.9	39.0–39.4	39.5–39.9	40.0–40.4	40.5–40.9	41.0–41.4	41.5–41.9	42.0–42.4	42.5–42.9	43.0–43.4	43.5–43.9	44.0–44.4	44.5–44.9	45.0–45.4
	(Percent)																																		
75 Cows; Hay Crushed, Field Cured and Baled:																																			
June 1				2		6	7	6	13	23	21	8	10	4																					
June 15						2	12	31	29	19	7																								
June 30			4	6	15	17	35	23																											
75 Cows; Hay Crushed, Baled and Barn Dried:																																			
June 1												2	12	67	19																				
June 15											2	23	75																						
June 30										44	54		2																						
100 Cows; Hay Crushed. Field Cured and Baled:																																			
June 1																				2		2		2	2	2	2	8	10	23	11	23	8	5		
June 15																		2	8	6	10	2	11	11	11	11	10	10	8							
June 30									2	2		2		6	15	8	12	19	17	13	4															
100 Cows; Hay Crushed. Baled and Barn Dried:																																			
June 1																											2			2	4	8	17	27	36	4
June 15																									8	22	19	23	19	9						
June 30											2								2		4	29	34	29												
Cows Vary; Hay Crushed. Field Cured and Baled:																																			
June 1		4		6	6	19	15	18	14	2	4	8	2		2																				
June 15												4	4	8	13	4	13	24	15	11	2		2												
June 30														4	4	2	2	2	4	13	12	12	13	6	14	12									
Cows Vary; Hay Crushed. Baled and Barn Dried:																																			
June 1											4	10	6	17	17	12	12	8	4	4	4	2													
June 15																								2	11	27	35	8	11	6						
June 30																												2	2		50	46				

without heat system is also shown in Table 6. Variation in gross farm income was greater with the crushed field cured, baled system. A hay-in-a-day type system reduced the variability in income due to year-to-year weather differences. Moving the date of cut from June 1 to June 15 and from June 15 to June 30 reduced average gross income by $636 and $1,161, respectively, with the crushed field cured, baled system. Results were similar as date of cut was advanced from June 1 to June 30 with the other forage harvest system.

100 Cows and Selected Hay Harvesting Systems

The gross income distribution with 100 cows was quite similar to that with 75 cows (Table 6). The system with the shorter cut-to-storage time reduced the income variability over time. For both harvest systems, gross income declined as date of cut was moved later than June 1. Moving from June 1 to June 15 with the crushed, field cured, baled system lowered income by $2,937. Going from June 15 to June 30 lowered income by $3,535. The hay-in-a-day system showed changes which lowered gross income by $3,155 and $2,420, respectively.

Number of Cows Varying and Selected Hay Harvesting Systems

When the size of the herd was allowed to adjust in the model to the production of eatable forage, the average gross income increased as date of harvest moved from early to late June. (Table 6). For the crushed, field cured system the June 1 to 15 increase was $4,772; and the June 15 to June 30 increase was $2,264. The income increases for the barn dried system was $5,692 and $2,158 respectively for these time periods.

Influence of Date of Cut and Weather Pattern on Net Farm Income

The level of net farm income and the change in net farm income associated with the advancing date of cut were the most relevant considerations in assessing alternative management systems. The analysis showed average net farm income and variations in net farm income associated with 52 weather patterns, by date of harvest, for each of 3 herd sizes, and for each of 2 hay harvesting systems. No effort to analyze income differences between the 3 different herd size situations was made because this study was not designed to investigate scale economics. Therefore, the net income analysis will be presented by herd size options.

75 Cows and the Crushed, Field Cured, and Baled Hay Harvest System

Table 7 illustrates the variations in net farm income associated with the 52 weather patterns for the 3 dates of cut. Considerable varia-

Table 7. Percentage of Times During Weather Patterns, 1910-1961, That Specified Net Farm Income Would Have Been Obtained, by Starting Date of Cut

Size of Herd, Hay Harvest System, Starting Date of Cut	Thousands of Dollars																										
	Under 9.5	9.5–9.7	9.75–9.9	10.0–10.24	10.25–10.49	10.50–10.74	10.75–10.99	11.00–11.24	11.25–11.49	11.50–11.74	11.75–11.99	12.00–12.24	12.25–12.49	12.50–12.74	12.75–12.99	13.00–13.24	13.25–13.49	13.50–13.74	13.75–13.99	14.00–14.24	14.25–14.49	14.50–14.74	14.75–14.99	15.00–15.24	15.25–15.49	15.50–15.74	15.75–15.99
	Percent																										
75 Cows; Hay Crushed, Field Cured and Baled:																											
June 1	2		2	2	4	20	8	19	23	12	6	2															
June 15				2		2	10	13	21	21	8	15	6	2													
June 30	6	4	10	10	8	19	14	19	10																		
75 Cows; Hay Crushed, Baled and Barn Dried:																											
June 1												2	33	50	15												
June 15													6	23	71												
June 30										10	32	58															
100 Cows; Hay Crushed, Field Cured and Baled:																											
June 1										2	2		2	6	2	13	8	15	23	15	8	4					
June 15									2		2	8	2	8	10	2	8	13	10	10	11	5	5	4			
June 30	5		2	4	8	8	8		10	5	21	10	4	8	5	2											
100 Cows; Hay Crushed, Baled and Barn Dried:																											
June 1																				2			8	46	40	4	
June 15																					8	15	13	25	25	12	2
June 30											2			2	2	19	21	23	21	8		2					
Cows Vary; Hay Crushed, Field Cured and Baled:																											
June 1	2	4	4	8	17	16	17	16	4	4	6	2															
June 15							2	2	2	2	8	10	12	19	12	15	6	4	6								
June 30	6	2	6	2	4	10	6		2	11	11	10	10	6	4	4	4	2									
Cows Vary; Hay Crushed, Baled and Barn Dried:																											
June 1										4	2	10	8	19	13	19	10	8	5	2							
June 15																					2	2	19	77			
June 30							2									2		13	18	16	19	13	13	4			

tion in net income exists within each of the 3 harvest dates. The greatest variation in net income exists when using the June 1 starting date, and the range in incomes covers a spand of $3,500. The average net income for all 52 weather patterns by date of cut is shown in Table 8. The averages ranged from $10,557 for June 30 to a high of $11,524 for June 15. The differences between these mean incomes are also present in Table 8. Moving from June 1 to June 15, income increased $477. Comparing June 15 and June 30, net income decreased by $967. These differences are significantly different statistically and probably economically over time. However, the distribution of incomes as shown in Table 7 is so great that farmers may not be able to associate the differences with date of cut.

75 Cows and the Crushed, Baled, and Barn Dried Without Heat Hay Harvest System

Income variations associated with 52 weather patterns by date of harvest are shown in Table 7. Compared with the above system, there is far less income variation for each date of cut. The average differences by date of cut ranged from $11,992 to $12,780 (Table 8). The differences among the net incomes of the 3 dates of cut were statistically different. The June 1 and 15 dates of harvest result in incomes quite similar and considerably higher than June 30. Farmers probably would recognize this difference in their income.

100 Cows and the Crushed, Field Cured, and Baled Hay Harvest System

An outstanding observation about the analysis of this harvesting system is the variability of net farm income (Table 7). Just as with the smaller herd size, farmers would experience large variations from year to year in net income using this hay system. Average income (Table 8) is about the same for the 2 early dates of cut and declines about $2,000 when cutting begins on June 30. The difference in income was statistically different and would be expected to be economically important to farmers.

100 Cows and the Crushed, Baled, and Barn Dried Without Heat Hay Harvesting System

This hay-in-a-day system reduces the variability in net income (Table 7). Again, the first 2 harvest dates are almost identical in average net farm income (Table 8). As the date of cut is advanced to June 30, income decreases by about $1,600. Farmers would recognize this difference due to the limited variability in net income within each date of cut.

Number of Cows Varying and the Crushed, Field Cured, and Baled Hay Harvest System

The range of variation in net incomes for this harvest system with

Table 8. Net Farm Income and Differences by Date of Cut, Average of 52 Weather Patterns, for 2 Harvest Systems and 3 Herd Sizes

Harvest System and Date of Cut of Hay	Number of Cows in Herd: 75 — Net Income: Average	Mean Difference*	100 — Net Income: Average	Mean Difference*	Varied with Forage Production — Net Income: Average	Mean Difference*
	(Dollars)		(Dollars)		(Dollars)	
Hay Crushed, Field Cured and Baled:						
June 1	11,047		13,619		10,735	
		477		—60†		1,909
June 15	11,524		13,559		12,644	
		—967		—2,145		—1,194
June 30	10,557		11,414		11,450	
Hay Crushed, Feld Cured and Barn Dried:						
June 1	12,572		15,200		12,884	
		208		—83†		2,172
June 15	12,780		15,117		15,056	
		—788		—1,600		—884
June 30	11,992		13,517		14,172	

* Average difference in net income resulting from postponing date of beginning harvest from earlier date to later date.
† Not statistically significant at the 95 percent level. All other significant.

cows varying was not different than when cow numbers were stipulated (Table 7). Income increased considerably when date of cut was moved from June 1 to June 15. Moving from June 15 to June 30, while more profitable than June 1, was less profitable than June 15 by almost $1,200.

Number of Cows Varying and the Crushed, Baled and Barn Dried Without Heat Hay Harvesting System

Table 7 illustrates the variation of net incomes by date of harvest. Relative to the other machinery systems there is very little difference in income distribution. June 15 is again the optimum economic date of harvest and is much more profitable than either June 1 or June 30.

Most Profitable Hay Harvest Date of Cut and System

Of the 6 possible comparisons of date of cut shown in Table 8, June 15 was superior to June 30 for each harvest system and each herd size option. Since only 3 dates of starting were tested, it was impossible to select the precise optimum date of cut. June 30 is definitely inferior. However, based on the results, the optimum economic harvest beginning date falls after June 1 and before June 30. Selecting the harvest starting date to maximize net income seems to be an adjustment which farmers should easily be able to make. The only conflicting goal which might arise is one of competition for the use of productive resources during the harvest season. Labor may be needed to plant corn, and its return may be considerably greater in this use than in adhering to a strict time sequence for forage harvesting.

Differences associated with shifting through the 3 dates of cut were not found to be large. Year-to-year differences in the weather pattern had a marked influence, particularly with the system using natural field curing. However, farmers committed to a machinery harvest system can select the approximate starting date to obtain the greatest net income.

The second problem tested in this study was one of appraising several machinery systems for harvesting forage. These were reduced to the 2 representative systems in Table 9; 1 system represented field drying; the other represented the more intensive single-day artificial drying system. The use of the hay-in-a-day system resulted in a marked drop in year-to-year variation in income variability (Tables 6, 7). As shown in Table 9, the artificial (without heat) drying method resulted in higher net farm income when all other factors were held constant. This indicated that some farm income advantage can be obtained using a harvest system that shortens the time between cut and storage. The system tested in this study involved considerable additional investment compared with field drying, and the problem of capital accumulation was not studied. For the same beginning date of harvest, net farm income could be increased by amounts varying from over $1,200 to under $3,000 (Table 9). These are magnitudes that warrant the consideration of dairy farmers in economic planning.

Table 9. Net Farm Income and Differences by Harvest System, Average of 52 Weather Patterns, for 3 Dates of Cut and 3 Herd Sizes

Number of Cows in Herd and Harvest System	Starting Date of Cut					
	June 1		June 15		June 30	
	Net Income		Net Income		Net Income	
	Average	Mean Difference	Average	Mean Difference	Average	Mean Difference
	(Dollars)		(Dollars)		(Dollars)	
75						
Hay Crushed, Feld Cured and Baled:	11,047	1,525	11,524	1,256	10,557	1,435
Hay Crushed, Feld Cured, Barn Dried:	12,572		12,780		11,992	
100						
Hay Crushed, Field Cured and Baled:	13,619	1,581	13,559	1,558	11,414	2,103
Hay Crushed, Field Cured, Barn Dried:	15,200		15,117		13,517	
Varied with Forage Production						
Hay Crushed, Field Cured and Baled:	10,735	2,149	12,644	2,412	11,450	2,722
Hay Crushed, Field Cured, Barn Dried:	12,884		15,056		14,172	